Chapter 2:

AFRICAN CLIMATE CHANGE: PAST AND FUTURE

2.0 Introduction

This chapter provides information on how African climate has changed in the past, and how it is projected to change in the future under global warming. Box 2.1 provides definitions of some terms that the reader will encounter in the text.

Questions:

- *Is climate change occurring in Africa? If so, why?*
- *What are the likely changes in climate that Africa faces in future?*
- *What method and tools are available to assess the changes?*
- *And what is the certainty level associated with future projections?*

Box 2.1: Definitions of Climate, Climate Variability and Climate Change

Climate: This is the long-term average weather conditions (usually taken over a period of more than 30 years as defined by the World Meteorological Organization, WMO) of a region including typical weather patterns such as the frequency and intensity of storms, cold spells, and heat waves.

Climate Variability: Variations in the mean state and other statistics (e.g. standard deviations or the occurrence of extreme events) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural external processes outside the earth system, or to natural or anthropogenic internal forcing.

Climate Change from the IPCC point of view refers to any change in climate over time, whether due to natural variability or as a result of human activity.

This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), which defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'

2.1 Global Climate Change

It is well known that the global mean surface temperature has increased (by about 0.07°C per decade in the past 100 years (IPCC, 2007). However, the increase has been more rapid about 0.18°C per decade in last 25 years, with the last decade (2001–2010) being the warmest decade on record (Fig 2.1). The average temperatures over the decade is 0.46°C above the 1961–1990 mean, and 0.21°C warmer than the previous decade (1991–2000). In turn, 1991–2000 was warmer than previous decades, consistent with a long-term warming trend (WMO, 2011). The surface warming occurs everywhere (except in the eastern Pacific, Southern Ocean and parts of Antarctica), but the land is warming faster than the ocean (IPCC, 2007). The Intergovernmental Panel on Climate Change (IPCC) has projected that global mean temperatures may increase by between 1.4 and 5.8°C by the end of the 21st century (IPCC, 2007).

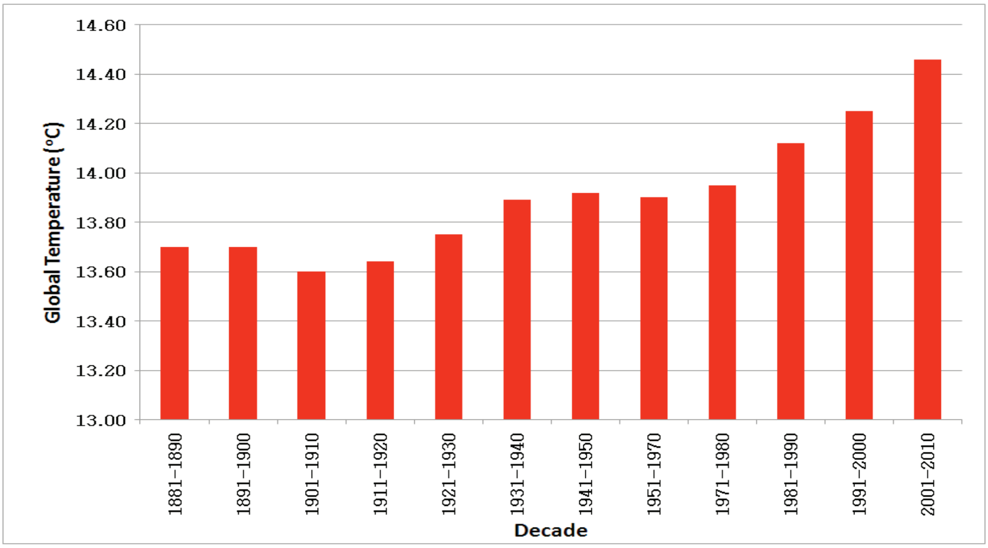


Figure 2.1: Decadal global average combined land-ocean surface temperature (°C), redrawn from WMO, 2011

Consistent with the global warming, mountain glaciers and snow cover have declined in both hemispheres. The global average sea level has risen since 1961 at an average rate of 1.8 mm per year and since 1993 at 3.1 mm per year, with contributions from thermal expansion and melting glaciers and ice caps, and the Greenland and Antarctic ice sheets. Significant increase in precipitation has been observed in the eastern parts of North and South America, northern Europe and northern and central Asia. The frequency of heavy precipitation events has increased over most land areas, which is consistent with warming and increases in atmospheric water vapour.

At the same time, there has been some drying in the Sahel, the Mediterranean, southern Africa and parts of southern Asia (IPCC, 2007). Widespread changes in extreme events have been observed. For example, cold days, cold nights and frost are less frequent, while hot days, hot nights, and heat waves are more frequent. More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and sub-tropics. There is also evidence of increased intensity of tropical cyclone activity in the North Atlantic since about 1970 (Thornton et al., 2008).

2.2 Climate Variability and Changes in Africa

2.2.1 Spatial variability

Africa experiences a wide variety of climate regimes, in which its location, size, and shape play key roles. Rainfall amount, duration and seasonality are the most important factors in differentiating the African climate regimes, which vary from the Indian Ocean to Central Africa and from the North to the South, ranging from humid equatorial regimes, through seasonally-arid tropical regimes, to sub-tropical Mediterranean-type climate (Hulme et al., 2001). The poleward extremes of the continent experience winter rainfall associated with the passage of mid-latitude air masses. Northern Africa is made up of both arid and semi-arid climatic zones, with a wetter coastal strip (Fig. 2.2).

In West Africa, the climates range from humid equatorial conditions at the coast to arid conditions in the northern Sahelian countries and have a wide precipitation range decreasing from the coast towards inland. In the Sudano-Sahelian region, the climate is generally dry and characterized by two seasons while the Southern humid areas have one season. Central Africa's climate varies from tropical-dry to equatorial.

Rainfall is highly variable across Eastern Africa ranging from about 100 mm/year in northeastern Ethiopia to about 2500 mm/yr in parts of northern Tanzania, with an average annual precipitation of 920 mm/year (Fig 2.2). Large parts of Eastern Africa are arid or semi-arid, with annual rainfall below 500 mm. Southern Africa's climate also exhibits variation in climate zones, from warm desert to humid subtropical and high levels of variability exists within the zones (Tadross et al., 2009).

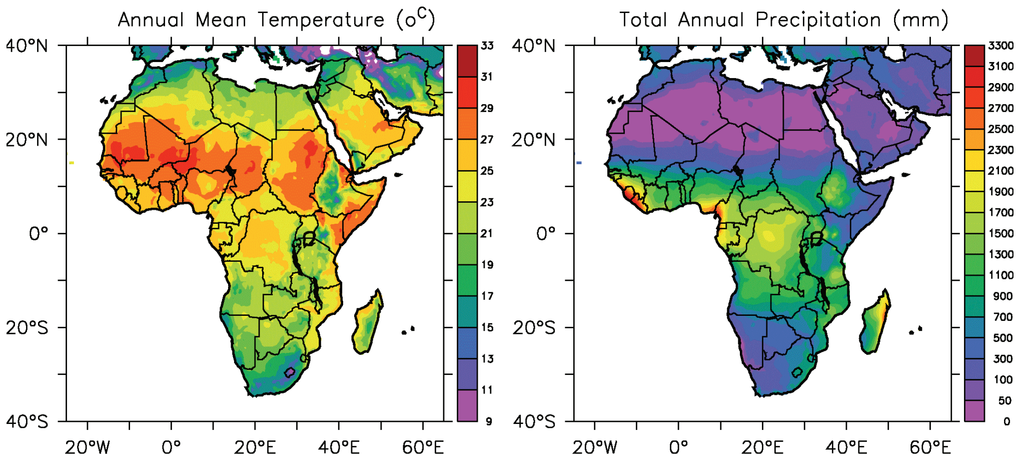


Figure 2.2: Spatial distribution of annual mean temperature (left panel) and total annual rainfall in Africa (right panel), averaged over 1901 - 2010. (Data source: Met Office Hadley Centre, UK, and Climatic Research Unit, University of East Anglia, United Kingdom).

African climate is influenced by planetary scale features such as the Hadley Circulation, the influences of the Atlantic and Indian Ocean monsoons, the Inter-Tropical Convergence Zone (ITCZ), Sea-Surface Temperature (SST), and El-Niño Southern Oscillation. For instance, across the Kalahari and Sahara deserts, precipitation is inhibited by downward motion in the Hadley Circulation throughout the year. In contrast, moderate to heavy precipitation associated with the Inter-Tropical Convergence Zone (ITCZ) characterizes equatorial and tropical areas. The spatial variability of African climate is also influenced by the presence of large contrasts in topography, and the existence of large lakes in some parts of the continent (Semazzi and Sun, 1995). Hence, the climate of the individual country county in Africa is influenced by latitude, atmospheric circulation diurnal position and by localized factors such as topography and the presence of large bodies of water.

2.2.2 Temporal variability

All African climates exhibit differing degrees of temporal variability, particularly with regard to rainfall. Variability can be seasonal, inter-annual, and decadal or in longer time scales (Lebel and Ali, 2009). High rainfall variability is a major determining feature of the African drier climates (arid and semi-arid). Rainfall is relatively high and reliable over the central and coastal parts of the sub-region but significant variation exists (e.g. Doula in Cameroon averages 3,850 mm and N'Djamena in Chad, 500 mm per year). Rainfall is more variable towards the north. Temperatures are high (24-26°C) in the low-lying coastal forests varying little due to persistent cloud, while in the high-relief mountainous areas, annual temperatures are lower and more variable (19°C and 24°C). The semi-arid zones experience a high temperature range between day and night.

2.3 Climate Changes

2.3.1 Trends in temperature

Most parts of Africa have experienced temperature increase (about 0.70°C) in the last century (IPCC, 2001). On regional scales, observation shows increases in temperature over the Sahel, tropical forests, southern Africa, eastern Africa and north Africa (Fig 2.3: Meehl et al., 2000; Boko et al., 2007). The temperature of African tropical forest increases by 0.29°C since 1960, and that of Sahel increased by 0.2°C-0.3°C during the 1990s (Hulme et al., 2005; Boko et al., 2007). Collins (2011) reported significant increasing temperature trends in all African regions during the past two decades (1995-2010). In southern Africa, increase in temperature between 0.1-2°C was reported for period 1900-1995 (Boko et al., 2007; Hulme et al., 2001). A temperature increase of between 0.2-0.3°C was reported for eastern Africa (Hulme et al., 2001). On local scales, temperature decreases have been observed in Cameroon and in parts of Malawi, Senegal and Nigeria (Hulme et al., 2001; Hulme et al., 2005). Hasanean (2001) found a temperature increase in Tripoli, Libya, but a temperature decrease in Alexandria, Egypt. Domroes and El-Tantawi (2005) observed temperature decrease in northern Egypt, but increase in the southern Egypt. Odjugo (2010) reported temperature increase of 1.2°C in Port Harcourt (a Coastal city) and 2°C in Nguru (a semi-arid city of Nigeria) between 1901 and 2005.

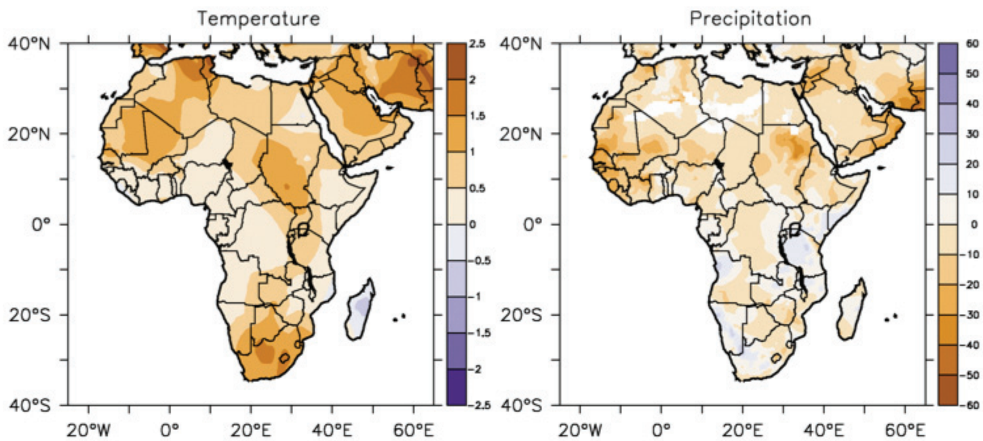


Figure 2.3 Mean linear trends in annual temperature (°C century–1) and annual rainfall (% century–1), calculated over the period 1901–2010. (Data source: Met Office Hadley Centre, UK, and Climatic Research Unit, University of East Anglia, United Kingdom).

More recently, WMO reported that 2010 was the warmest year on record in Africa, particularly, for West Africa, the Saharan/Arabian region, and the Mediterranean (WMO, 2011). The year was exceptionally warm in most of Africa. Temperatures averaged over Africa were 1.29°C above the long-term average, breaking the previous record by 0.35°C. Continental monthly anomalies exceeded +1.5°C in each of the five months from December 2009 to April 2010, peaking at +2.12°C in February; the previous largest monthly anomaly on record was +1.44°C in April 1998. All twelve months of 2010 were at least 0.7°C above normal. While temperatures were well above average throughout Africa, they were especially exceptional in the northern half of the continent (extending into the Arabian Peninsula), where the Saharan/Arabian region was 2.22°C above normal, 0.89°C above the previous record and the largest annual anomaly ever recorded for any sub-region outside the Arctic. The Mediterranean region also had its warmest year on record with Tunisia equaling its previous warmest year.

2.3.2 Trends in rainfall

In general, Africa has been drier in the last few decades (Nicholson, 2001; L'Hóte et al., 2002; Oguntunde et al., 2006), however, while some regions have experienced a decrease in rainfall, some have experience an increase in rainfall. For instance rainfall has decreased in the Horn of Africa (Fischer et al., 2005), in Botswana, Zimbabwe, the Transvaal, and in the Sahel during the period from 1961 to 1990 (Hulme et al., 2005), but significant increase in rainfall is reported for South Africa (Mason et al., 1999). In the Volta Basin encompassing six countries in West Africa, rainfall increased at the rate of 0.7 mm/yr^2 or 49 mm/yr between 1901 and 1969, whereas a decrease of 0.2 mm/yr^2 (6 mm/yr) was estimated for 1970-2002 sub-series (Oguntunde et al., 2006). In central Africa (Congo basin), precipitation reduced slightly (2-3%) but heavy rainfall events increased over Angola, Namibia, Mozambique, Malawi and Zambia between 1931 and 1990 (Sivakumar et al., 2005; Boko et al., 2007). The Sahel has experienced a decrease in rainfall from 1970 to 2000, with recurrent droughts; a major drought lasted from 1972-1984 (UNEP, 2002). Rainfall in the Sahel has increased since the end of the 1990s, although the annual average rainfall is still as low as during the drought of the 1970s (Mahe and Paturel, 2009).

2.3.3 Trends in extreme climate events

While decreases in precipitation may lead to drought, increases in precipitation can lead to floods. In Africa, the frequency and severity of droughts and floods have increased over the past 30 years. Droughts have increased in frequency and intensity in Eastern Africa (FAOSTAT, 2000; UNEP, 2002), where frequent droughts have occurred in each decade over the past 50 years in the region (FAOSTAT, 2000). The East African drought of 2011 is proving to be one of the worst that Ethiopia has faced in 50 years. In the Central Africa and Sahel, droughts have become more frequent since the late 1960s. An increase in rainfall extremes has been observed for southern Africa and the Guinean coast. Increase in frequency of rain days, heavy rains often accompanied by severe floods (as in 1999/2000 in Mozambique). Devastating flooding events in southern Nigeria has been linked with the progressive increase in August rainfall over the region in the last five decades (Adefolalu, 2001). The various changes, increases and decreases in climate variables within a location and between locations, increases the challenges already posed by climate variability in Africa (Fig 2.4; Table 2.1).

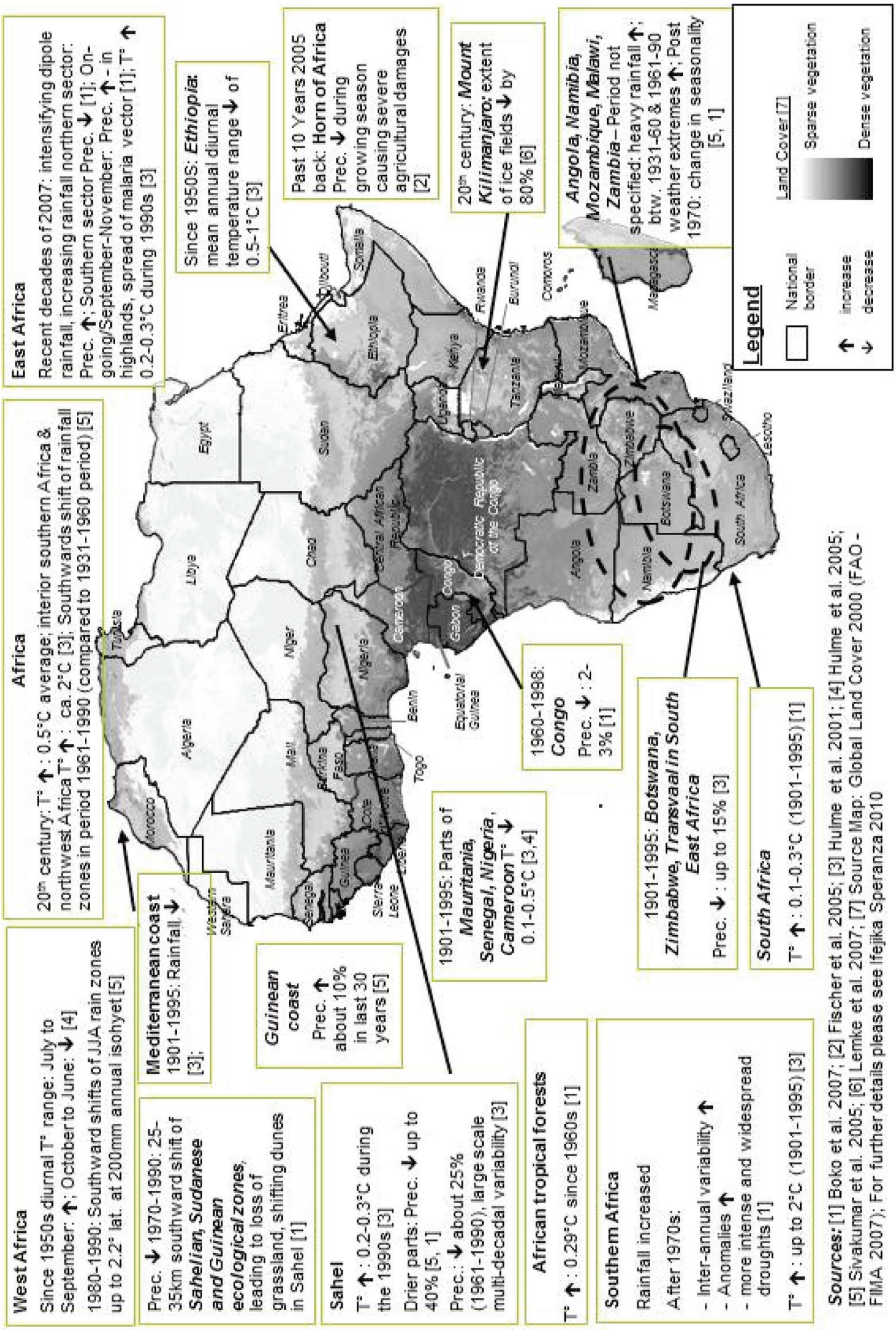


Fig. 2.4: Observed Climate Change Impacts in Africa (source: Chinwe Ifejika Speranza, 2010)

Table 2.1: Observed changes in climate by sub-region, summarized from IPCC Fourth Assessment Report

Region	Observed Trends	Extremes
West Africa	• Greater warming trend since 1960s (changes not uniform) • Increase in number of warm spells (1961-2000) • Decrease in the number of extremely cold days (1961-2000) • Decline in annual rainfall since end of 1960s (e.g. decrease of 20 to 40% noted between 1968-1990,), with an increase again since 1990, but still significantly below 1960s levels • Inter-annual variability has become larger since 1980 • Decline in mean annual precipitation of around 4% in tropical rain-forest zone (1960-1998)	• Increased incidence of drought 1900-2002
Central Africa	• Greater warming trend since 1960s (changes not uniform e.g. decadal warming rates of 0.29°C in the African tropical forests) • Declines in mean annual precipitation in the tropical rain-forest zone for period 1960 to 1998 (e.g. around 3% in North Congo and 2% in South Congo) • 10% increase in annual rainfall along the Guinean coast during the last 30 years	
East Africa	• Greater warming trend since 1960s (changes not uniform) • Decreasing trends in temperature from weather stations located close to the coast or to major inland lakes • Intensifying dipole rainfall pattern on the decadal time-scale, characterized by increasing rainfall over the northern sector and declining amounts over the southern sector	• 1997/98 El Nino • 1999/2001 La Nina Drought • 2009/2010 Drought
Southern Africa	• Greater warming trend since 1960s (changes not uniform e.g. 0.1 to 0.3°C in South Africa) • Increase in number of warm spells (1961-2000) • Decrease in the number of extremely cold days (1961-2000) • No long-term trend in annual rainfall has been noted, but increased inter-annual rainfall variability has been observed in the post-1970 period • In certain parts (e.g. Angola, Namibia, Mozambique, Malawi, Zambia) there is evidence of changes in seasonality	• More intense and widespread droughts reported • In certain parts (e.g. Angola, Namibia, Mozambique, Malawi, Zambia) a significant increase in heavy rainfall events has been observed associated with flooding

2.4. Causes of Climate Variability and Change

Climate variability and change is driven by natural and anthropogenic factors. Here we distinguish between these factors, and discuss the African contribution to the anthropogenic factors.

2.4.1 Natural versus anthropogenic climate forcing

The climate system is driven by the sun's energy and regulated by natural processes and cycles in the Earth system. These include the carbon cycle and greenhouse effect, orbital cycles, ocean currents that distribute warmer and colder water around the globe, and atmosphere-ocean interactions that moderate temperature. The natural processes include variations in solar sunspot activities, the earth-sun geometrics, volcanic eruption, ocean-atmosphere interaction integration, and continental drift. The signature of these natural forcing is evince on inter-annual variability of global and regional atmospheric features like the El-Nino/La Nina Southern Oscillation (ENSO), the African jet streams, the tropical Easterly jet, the North Atlantic Oscillation, the southern annular mode, monsoons, cyclones and subtropical anticyclones, and the easterly/westerly wave perturbations - they all influence regional weather patterns and climate variability in Africa (Knippertz et al., 2003; Bowden and Semazzi, 2007; Christensen et al., 2007; Paeth and Thamm, 2007; Patricola and Cook, 2009).

However, the influence of these atmospheric features on African climate varies from one region to the other. In Eastern Africa, the ENSO is a major feature in the sub-region's climate variability, causing floods and droughts (UNEP, 2002). In southern Africa, rainfall is strongly influenced by the Inter-Tropical Convergence Zone (ITCZ), the Southern Oscillation Index (SOI), the Antarctic Oscillation (AAO) and also the ENSO. In West Africa the climate is influenced by atmospheric jets, monsoon, and is very sensitive to global SST and regional land surface processes. The climate of northern Africa is also distinguished by an especially strong coupling between the atmosphere and the land surface (e.g., Xue and Shukla, 1993; Xue and Shukla, 1996; Koster et al., 2004; Patricola and Cook, 2007).

It is generally accepted that the anthropogenic climate forcing is the main cause of the climate change (IPCC, 2007). This includes greenhouse gases, aerosols, and land surface changes. Studies have shown that while increase in the concentration of the greenhouse gasses would increase the global temperature (global warming), an increase in atmospheric aerosol would decrease it (global dimming and global cooling), but changes in the land cover could either increase or decrease the local temperature.

The increase in the GHG (i.e. CO_2, Methane, etc) since industrialization in the 1900s is the major cause of the ongoing global warming. The increase has been attributed to a rise in the burning of fossil fuels, high population growth rates, increasing reliance on fossil fuel-driven growth technologies, and land use effects (particularly urbanization, agriculture and deforestation). Further increases in GHG levels are expected in future, particularly as developing countries also become more industrialized. However, any increase in GHG enhances the "greenhouse" properties of the earth's atmosphere. These gasses allow solar radiation from the sun to travel through the atmosphere but prevent the reflected heat from escaping back into space which causes the earth's temperature to rise.

2.4.2 African contribution to the anthropogenic climate forcing

2.4.2.1 Greenhouse Gases (GHGs)

While the developed countries are responsible for increase in GHGs, there are various activities in Africa that could contribute to the increase. For instance deforestation would increase the amount of CO_2 in the atmosphere, because when forests (which act as major carbon store) are cleared and the trees are either burnt or rot, the stored carbon is released as CO_2 into the atmosphere (Houghton, 2005; Stern, 2006). Other anthropogenic ways through which Africa contributes to increase in GHGs include the release of black carbon (including gas flaring and bush burning), methane from waste (poor waste management), and many industrial activities. However, studies have shown that African contribution to the increase in GHGs is very small when compared to that of other more developed continents.

2.4.2.2 Landuse changes

Land-use changes (such as deforestation, desertification, and urbanization) also increase the atmospheric temperature. These land use changes remove the vegetative cover that absorbs the shortwave radiation, thereby, leading to global warming (Glasdottir and Stocking, 2005). Development is a main cause of these land-use changes in Africa. For instance, people cut down trees for economic purpose: to expand cities, build houses, and create large-scale farming. The band of West African forests that once extended from Guinea to Cameroon is virtually gone. Deforestation has been most severe in Nigeria, where more than 410,000 hectares of forest are lost to desertification annually. The annual deforestation rate has increased from 2.7 percent of the country's land from 1990-2000 to 3.3 percent in 2000-2005; and currently, less than 12.2 percent of the country land is forested (FAO, 2009). Within 2000 and 2005, Ghana lost an average of 115,000 hectares of forest per year, which amount to 2.0 percent of the country's land. In general, over the last 15 years, West Africa has lost almost 12 million hectares (two times the size of Togo) of tropical forest (FAO, 2009); the annual deforestation rate is 1.17 percent of the total land per annum. Even though, African forests constitute only 16 percent of the world's total, the deforestation rate in Africa is more than six times the world's average (FAO, 2009). Abiodun et al., (2007) used regional climate model to show that changes in land-use may be major contributors to the persistence of the observed drought over the West African sub-region.

2.5. Future Climate Projections for Africa

Various future climate projections are available over Africa. This section presents methods and sources of climate projection before discussing the future climate projected over the continent.

2.5.1 Tools for future climate projections

Climate studies use different climate models to project the future climates, but the most acceptable tools, used in IPCC reports, are Global Climate Models (GCMs) and Regional Climate Models (to downscale results of GCMs). Distinguish from General Circulation Models. It should be noted that a General Circulation Models (GCMs) are mathematical equations to represent the general circulation of the planetary atmosphere or the oceans. These equations are the basis for complex computer programs commonly used for simulating the atmosphere or ocean of the Earth. Atmospheric and Oceanic GCMs (AGCM and OGCM) are key components of Global Climate Models along with sea ice and land-surface components. GCMs and global climate models are widely applied for weather forecasting, understanding the climate, and projecting climate change.

2.5.1.1 Global Climate Models (GCMs)

GCMs are the primary tools for simulating past climate and projecting the future climate using different climate forcing scenarios. They are complex computer models that represent interactions between the different components of climate such as the land surface, the atmosphere and the oceans. GCMs solve various complex equations and adopt parameterization schemes to represent atmospheric processes, and provide physically self-consistent explanations of observed climate variations on various time scales (IPCC, 2007; WGI, Chapter 8). Various studies have demonstrated that the models are capable of providing reliable climate projections for the future (IPCC, 2007). In making projections of climate change, several GCMs and scenarios of future emissions of greenhouse gasses are used to predict the future. This process generates a suite of possible future scenarios, each valid but some scenarios can be considered more likely than others.

2.5.1.2 Downscaling GCM output for regional and local impacts assessments

There is a need to downscale GCM outputs before using them for regional and local impact assessments. This is because GCMs typically work at a spatial resolution of 200-300 km, which is useful for projected future climate at a global scale. However, at a regional scale GCMs are less useful because they cannot resolve local scale features (for example, sea-breeze, lake-breeze, or mountain-induced flows) which play an important role in regional climate. This limits the application of GCM projections for assessments of change at the local or regional scales. Therefore, the technique of downscaling is typically used to produce projections at a finer spatial scale. Downscaling is effective because the GCMs are generally good at projecting changes in atmospheric circulation (high and low pressure) but do a poor job of translating that information into changes in rainfall.

There are two possible approaches for downscaling, namely: statistical and dynamical regional climate models. The statistical model uses statistical/empirical equations to represent the relationship between the large features and local climate variables at stations, while dynamical models use physically based laws (similar to those in GCMs) to represent the relationship. Each method has advantages and disadvantages, and both are used in IPCC assessments.

Development of projections of climate change involves the development of both climate and socioeconomic scenarios. "SCENARIO" is defined as a plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a "narrative storyline" (IPCC, 2007a).

Scenarios of future conditions relevant to analyzing different aspects of the climate change issue have always been an important component of the work of the Intergovernmental Panel on Climate Change (IPCC) because of their utility for representing uncertainties associated with anthropogenic climate change. For the first, second, third and fourth assessments reports, the IPCC provided the terms of reference, reviewed the scenarios, and ultimately approved them, while modeling teams around the world prepared the scenarios. Previous sets of IPCC scenarios were published in 1990, 1992, and 2000. In 2006, the IPCC decided that new scenarios would be developed for their future assessment reports by the scientific community and these scenarios should include adaptation, economic growth, demographic, and other societal variables that lead to emission scenarios. Rather than having the IPCC directly coordinate and approve new scenarios, the research community itself now coordinates the process of scenario development. The role of the IPCC is to "catalyze" the timely production of new scenarios by others.

In this new process, a small number of "benchmark" emissions scenarios (referred to as "representative concentration pathways" (RCPs) are identified for potential use by climate modeling groups. The process considers:

- Comparability to serve the various user communities;
- Results of scenario activities undertaken by the World Bank, the Food and Agriculture Organization (FAO), the Organization for Economic Cooperation and Development (OECD), the International Energy Agency (IEA), the World Meteorological Organization (WMO), and the UN Environment Programme (UNEP), and the possible future involvement of these organizations in scenario development;
- Transparency and openness of the scenario development process; and
- Increased involvement in the scenario development process of experts from developing countries and countries with economies in transition.

Development of Global Climate Scenarios

Box 2.2 below provides the steps in development of global scenarios.

Box 2.2: Steps in the Development of Global Scenarios for use by IPCC and other communities *(ref: IPCC, 2008 IPCC-XXVIII/Doc.8, Twenty-Eighth Session Agenda item: 11.3, Budapest, 9-10 April 2008)*

Step 1: Hold Expert Meeting to

- Proposed set of "benchmark concentration pathways" that will be used in initial climate model runs to provide simulated climate outputs;
- Describe key scientific and technical issues for coordinated development of new integrated scenarios;
- Plan for the relevant research communities to coordinate, organize, and communicate further actions towards the development of new integrated scenarios; and
- Develop a plan for increasing involvement of experts from developing countries and countries with economies in transition in the development of new scenarios, including funding and organizational aspects.

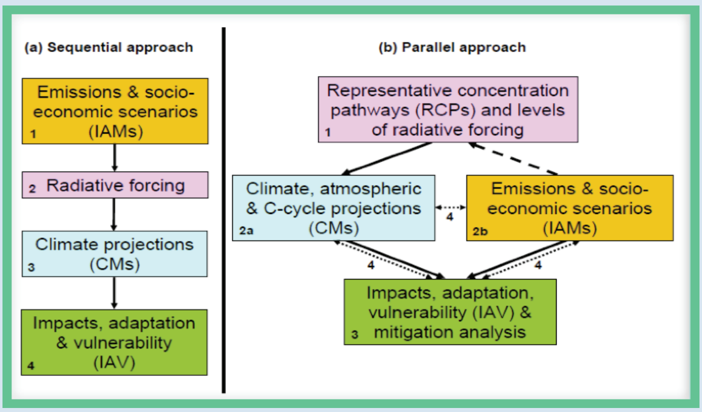
Step 2: Develop an integrated perspective for decision support and assessment by identifying and developing consistent scenarios to allow for:

- Assessments of impacts, adaptation, and vulnerability that are consistent with views of the evolution of climate change, which in turn should be consistent with views of emissions trajectories;
- Assessments of emissions that are consistent with views of socioeconomic drivers and landuse change and account for feedbacks from climate change impacts and policies to reduce both emissions and adverse impacts; and
- Impacts, adaptation, and vulnerability are assessed in a way that uses consistent information about socioeconomic drivers, technology, and land use change.

Step 3: Determine scenario characteristics and needs from an end-user perspective

- The characteristics and types of scenarios required must be determined in light of the needs of users of those scenarios. Users are categorized as "end users," policy- and decision makers who use scenario outputs and insights in various decision processes; and "intermediate users," researchers who use scenarios from a segment of the research community other than their own as inputs into their work;
- Time frame is important to users and requirements vary. Global scenarios for the IPCC has two time periods:
    - ◊ "near-term" scenarios that cover the period to about 2035 and are useful for better projections of regional climate change and associated impacts, evaluation of potential adaptation options; and exploration of opportunities and constraints on mitigation by taking account of economic, technological, and institutional factors; and
    - ◊ "long-term" scenarios that cover the period to 2100 and, in a more stylized way, can be extended to 2300 focus on considering options for the stabilization of anthropogenic influences on climate or the consequences of not doing so. They are often used for comparative analysis of the long-term climate, economic, environmental, and policy implications of different mitigation scenarios or pathways. They consider the role of feedbacks between climate and biogeochemistry, and nonlinearities in the climate system as well as in affected systems;

Step 4: Development of Representative Concentration Pathways (RCPs) to support a parallel process to expedite the development of integrated scenarios by enabling modeling the response of the climate system to human activities to proceed in parallel to emissions scenario development. (see Figure below: Approaches to the development of global scenarios: (a) previous sequential approach; (b) proposed parallel approach)



Step 5: Implement the parallel process for scenario development

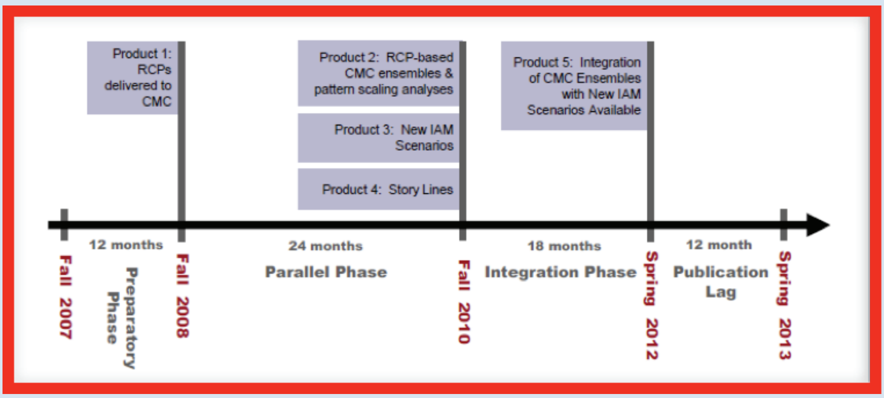
- As the identification of RCPs proceeds, the Climate Modeling community proceeds in parallel with new climate change projections by the IAM and IAV communities.
- The RCPs serve a limited role as inputs to various classes of CMs.
- The IAM community will simultaneously develop a range of completely new socioeconomic and emissions scenarios.
- Production of some new scenarios that are consistent with the RCPs will enable different teams of integrated assessment modelers to explore alternative technological, socioeconomic, and policy futures that are consistent with a given stabilization level,
- The IAV community conducts Impacts, adaptation, and vulnerability studies results become available from both the CM and IAM communities.

Step 6: Incorporating perspectives from developing and transition-economy countries

- Develop regional information for both IAV and mitigation analysis that touch on the special needs of developing and EIT countries in these areas.
- Identify barriers required to deepen, broaden and sustain DC/EIT participation in the scenario development process and in climate change assessments
- Develop a strategy for fundable opportunities to address these barriers in particular:
- The need for the expansion of expert and institutional scientific capacity in lower-income DCs, which lag behind both industrialized countries and larger DCs.
- In DCs that have more extensive scientific and modeling capacity proposed financial and technical support should be directed to enabling opportunities for downscaling of global models and up-scaling of regional/ national models;
- Concerted outreach and integration initiatives on the part of the broader international research and policy communities in address capacity and funding limitations to enhance DC/EIT participation

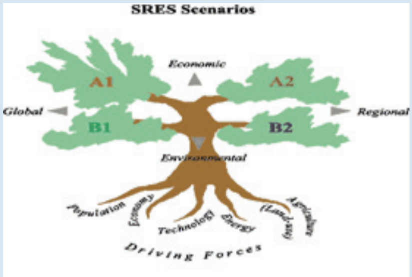
Following these steps in the coming years leading up to a possible IPCC Fifth Assessment Report (AR5), the following five principal scenario products are anticipated to be developed.

1. Representative concentration pathways (RCPs) and their associated emissions, produced by IAM teams and taken from the existing literature, discussed in Section III and anticipated to be completed by the fall of 2008;
2. Ensemble climate projections and pattern scaling anticipated to be available in the fall of 2010; these scenarios will be used for pattern scaling;
3. New scenarios developed by the IAM community anticipated to be available in the fall of 2010;
4. Global narrative storylines developed by the IAM and IAV communities anticipated to be available in the fall of 2010; and
5. Integrated new IAM scenarios consistent with the storylines with associated pattern-scaled climate scenarios anticipated to be available in spring 2012.



Box 2.3: Development of National Climate and Socio-economic Scenarios

To assess climate change impacts, the IPCC has developed family scenarios and storylines A1, A2, A3 and A4 (see figure) that describe demographic, social, economic, technological, environmental, and policy future for each one of these scenario families. Within each family, different scenarios explore variations of global and regional developments and their implications for trace gas emissions.



Schematic illustration of SRES scenarios

All four storylines and scenario families describe future worlds that are generally more affluent compared to the current situation. Each storyline assumes a distinctly different direction for future developments. They cover a wide range of key "future" characteristics such as demographic change, economic development, and technological change. Climate Change Impacts Assessors use a combination of the families to come up with scenarios for use in the climate change impacts assessment for their study site.

Having chosen the story lines appropriate for the country, the climate change scenarios for the country are developed by building a good data set of current climate extending for a period of not less than 30 years and then determining and accessing a Scenario Generator Model (e.g., MAGGICC-SENGEN or GRADs). MAGICC/SCENGEN, for example, is a coupled gas-cycle/climate model (MAGICC) that drives a spatial climate-change scenario generator (SCENGEN). It has built-in current and future climate data sets for the different regions of the world and General Circulation Model outputs (temperature, rainfall, etc) into the future (e.g., up to 2100). MAGICC has been the primary model used by IPCC to produce projections of future global-mean temperature and sea level rise. The flowchart below shows the directory structure of the MAGICC/SCENGEN software and useful information can be found in Wigley and Raper, (1992, 2001, 2002); Raper et al., 1996; Wigley, 1993, 2000 and Wigley et al., 2002

SCENGEN uses the scaling method of Santer et al., (1990) to produce spatial patterns of change from an extensive data base of atmosphere/ocean GCM (AOGCM) data. The scaling method is based on the separation of the global-mean and spatial-pattern components of future climate change, and the further separation of the latter into greenhouse-gas and aerosol components. Spatial patterns in the data base are 'normalized' and expressed as changes per 1oC change in global-mean temperature. These normalized greenhouse-gas and aerosol components are appropriately weighted, added, and scaled up to the global-mean temperature defined by MAGICC for a given year, emissions scenario and set of climate model parameters. For the SCENGEN scaling component, the user can select from a number of different AOGCMs for the patterns of greenhouse-gas-induced climate.

Climate Change scenarios of a region or a country are developed by combining current climate data with outputs from General Circulation Models extracted from the MAGGICC-SENGEN Model. The methodology requires first to run MAGICC in which one begins by selecting a pair of emissions scenarios, labeled as a reference scenario (R) and a policy scenario (P). Information in BOX 1 above guided the selection of reference and policy scenarios to use in this study. The user then selects a set of gas-cycle and climate model parameters and for these the default ('best guess') was chosen which is then carried through to SCENGEN. Running MAGICC then produces four output files to drive SCENGEN where the spatial consequences are explored.

Running the SCENGEN component of the software enables access to many GCM outputs (14 Models in the MAGGICC-SENGEN SG41 software) and the country's 30-year current or baseline climate data. The 30-year monthly baseline data is averaged. The averaged country temperature data is correlated with the GCM Model output of current temperatures and the correlation coefficient is determined. The 3 GCMs with the highest correlation coefficients are the ones that have closely estimated the baseline climate of the country and these are the Models recommended for use in the development of climate change scenarios for use in Impacts Assessment for the country. The climate change scenarios for the period 2000 to 2100 are then calculated by the combination of baseline climate parameters with the GCM Outputs for the period 2000 to 2100.

2.5.1.3 Identification of institutions undertaking downscaling of climate change scenarios

Table 3 provides the list of institutions that have downscaled climate change over the whole or regions of Africa. Note that only two of the institutions are in Africa, and both institutions are in South Africa. This underscores the need for capacity building on climate science in Africa**.** However, recently, an international project, called: "Coordinated Regional Downscaling Experiment (CORDEX)", was established to provide a coordinated high-resolution regional Climate projections for most land-regions of the world, with special focus on Africa (Giorgi et al., 2009). The project (CORDEX), which involves over 20 Regional Climate Modelling and Statistical Downscaling groups, would be implemented in two phases. The first phase would evaluate the performance of the downscaling methods for the regions, while the second phase would produce regionally downscaled climate projections for various regions at resolutions in the range of 50km-10km. The success of CORDEX means that, in future, a lot of information and data on regional climate change will be available online for impact assessment, adaptation and mitigation studies. Presently the Climate Research Group (CSAG) has a climate web-porter (ref), where downscaled regional climate data (using Statistical approach) can be downloaded over major cities in Africa.

Table 2.2: List of some Institutions downscaling future climate projection over Africa

Institution	Type of Downscaling	Reference (sample)
Climate System and Analysis Group (CSAG) University of Cape Town, South Africa www.csag.uct.ac.za	Statistical and Dynamical	Hewitson and Crane (2006) Tadross et al., (2005)
Department of Geography, Geoinformatics and Meteorology, University of Pretoria, South Africa	Dynamical	Engelbrecht et al., 2009
Earth System Physics Section International Centre for Theoretical Physics, Italy http://www.ictp.trieste.it/research/esp.aspx	Dynamical	Sylla et al., 2010
Department of Civil and Environmental Engineering, University of Connecticut, USA www.engr.uconn.edu	Dynamical	Alo and Wang, 2010
Department of Earth and Atmospheric Sciences, Cornell University, USA www.cornell.edu	Dynamical	Paricola and Cook, 2010
Geographical Institute, University of Wurzburg,Germany www.uni-wuerzburg.de	Dynamical	Paeth et al., 2008

2.5.1.4: How good are the tools over Africa?

Different models (both GCMs and RCMs) show different skills in simulating present-day climate. Evaluating a model against another is not an easy task; one model may better simulate monthly mean rainfall and temperature but it may not better simulate the daily frequency or diurnal cycle of rainfall (Collier and Bowman, 2004; Bergman and Salby, 1997). Some preliminary results from CORDEX indicate that most regional models capture the magnitude and timing of precipitation over Africa well, and the ensemble mean precipitation agrees with the observations very well. However, while some models are better than others at simulating the present-day observed African climate, this does not necessarily mean that they are better at simulating future change.

2.5.2: Projected future climate changes over Africa

Various studies have shown that the future climate change would hit Africa hard, but with different degrees over different parts of the continent. The IPCC (2007) provides a broad assessment of changes expected to 2100 in Africa for all climate scenarios, and the main message is that the entire African continent is very likely to warm during this 21st century. The warming is very likely to be above the global average in all seasons, with drier subtropical regions warming more than the moister tropics IPCC, 2007. In addition, the annual rainfall is likely to decrease in Mediterranean Africa, Northern Sahara, Southern Africa, but increase in East Africa IPCC, 2007.

Many downscaled regional climate projections have confirmed or refined the IPCC assessment over different regions of Africa. Over northern Africa, there is no consensus among the GCMs about how the elevated GHGs would change the rainfall during the summer in the late 21st century, but projections using regional climate models provide more robust information (Patricola and Cook, 2007, 2009, 2010; Sylla, 2010; and Alo and Wang, 2010). For West Africa, Patricola and Cook (2010) project wetter conditions (with possibility of about 50% increase in rainfall) in spring, drying in early summer (June and July), and wetter conditions again (except over Guinean Coast) in the late summer, with possibility of more flooding (Fig 2.5). These projections are consistent with those in other regional climate studies over the region. Patricola and Cook (2010) also predict wetter conditions over eastern Central Africa (i.e. Cameroon, Central African Republic, Congo, and Democratic Republic of Congo) in June, but drying during August through September, and drying over East Africa in later summer, but wetter in October. A general increase in heat stroke risk is projected over all northern Africa throughout May-October (Fig 2.5). The people in the Sahel region would be most vulnerable, with possibility of 160 days of heat stoke per year in the twenty first century. The next highest risk is with the people in central equatorial Africa, Somalia, Kenya, Uganda, Gabon, and the Guinean Coast.

Over southern Africa, Tadross et al., (2005) project drier conditions across the tropical western side of the subcontinent in summer, and wetter conditions towards the east in January-March. Hewitson and Crane (2006) predict that South Africa would experience increased summer rainfall over the central and eastern plateau, and to the east of the eastern escarpment, but the south-western Cape will experience drying in both summer and winter. Olwoch et al., (2007) predict drier conditions over South Africa in winter, due to a displacement of frontal rain-bands towards the south, but wetter conditions over the western to central interior of South Africa mid-summer. Engelbrecht et al., (2009) project less than 10% changes in the annual rainfall over South Africa, except in the south-western Cape of South Africa, where the annual rainfall would considerable decrease. The projection also shows that the Eastern South Africa would become drier despite the projected increase in summer rainfall, and that the central interior of South Africa is the only part of the country that would become wetter in the future climate.

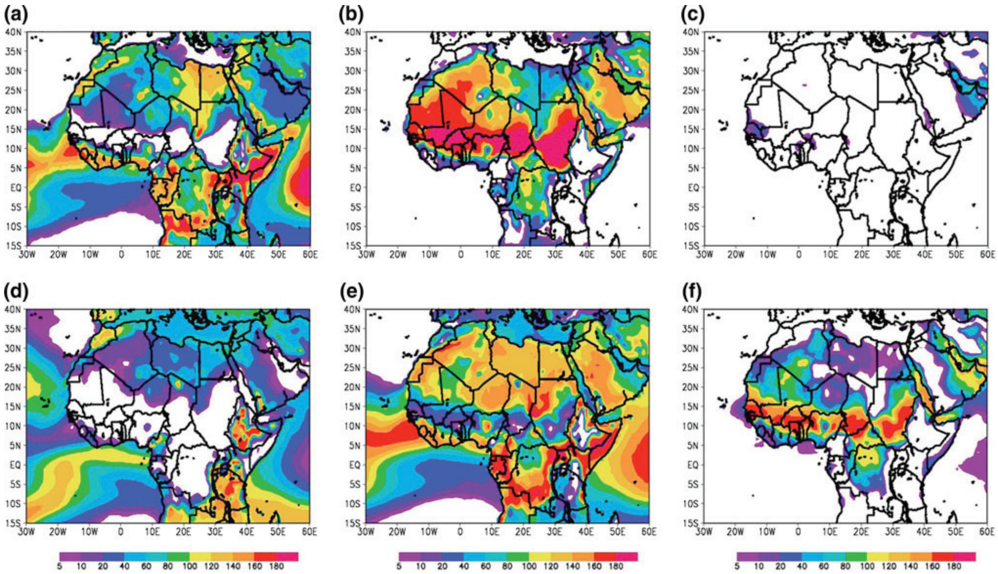


*Fig. 2.5: The number of days between May 1 and October 31 during which the maximum heat index occurring between 09Z and 15Z is in (**a**) low, (**b**) medium, and (**c**) high risk category in the twentieth century simulation, and the twenty-first century ensemble average number of days between May 1 and October 31 during which the maximum heat index occurring between 09Z and 15Z is in (**d**) low, (**e**) medium, and (**f**) high risk category (Patricola and Cook, 2010).*

2.5.3: How to handle the uncertainties in the future climate projections.

The issue of uncertainty is crucial to understanding past and future climatic change, especially when designing adaptation strategies that will benefit both present and future social, economic and ecological conditions. All climate projections, including seasonal forecasts, are presented in terms of the probability of particular climate conditions occurring in the future. Despite this uncertainty, this approach provides a framework which allows for assessing future risks, e.g. consideration of financial and other investment opportunities. To be able to assess risk, one needs to consider all sources of information. It is therefore essential that a probability framework is used to develop projections which incorporate different sources of information. The IPCC define four sources of uncertainty that currently limit the detail of the regional projections (IPCC, 2007):

1. **Natural variability:** Due to the challenges of observations (both in time and space), there is a limited understanding of natural variability. It is difficult to characterise this variability and the degree to which it may exacerbate or mitigate the expected background change in climate. This variability itself may change due to anthropogenic factors, e.g. increases in the frequency of droughts and floods;

2. **Future emissions:** Much of future projected change, at least in terms of the magnitude of change, is dependent on how society will change its future activities and emissions of greenhouse gases. Even so, the course is already set for a degree of change based on past emissions (at least another 0.6°C warming in the global mean temperature). Human responses to managing emissions may result in a projected global mean temperature change of between 1.5° and 5.6°C;

3. **Uncertainty in the science:** This is further complicated within Africa because of limited understanding of the regional dynamics of the climate of the continent. There may be aspects of the regional climate system which could interact with globally forced changes to either exacerbate

or mitigate expected change, for example land-use change. One consequence is the possibility of rapid nonlinear change, with unforeseen and sudden increases in regional impacts;

4. **Downscaling:** This term defines the development of regional scale projections of change from the Global Climate Models. Downscaling tools can introduce additional uncertainty, for example between downscaling using regional climate models and statistical techniques. This uncertainty limits the confidence in the magnitude of change, not the patterns of change, which are predicted with more certainty.

A challenge when using a single model is that only a limited number of future scenarios can be generated which can create the impression of a narrowly determined future that may not fully span the range of potential future change. It is therefore recommended that future change is expressed either as a range of future scenarios or as an average statistic (e.g. median) with some measure or recognition of the spread of possible future scenarios. The multi-model approach is essential in quantifying uncertainties for impact studies.